

# AOARD REPORT

Visit to the Department of Metallurgical Engineering, Tokyo  
Institute of Technology, 22 Sep 94

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AOARD



The Tokyo Institute of Technology is considered one of the premier technical universities in Japan. This report summarizes a visit to TIT's Department of Metallurgical Engineering to visit Professor Masao Takeyama, and Professor Takashi Matsuo. Professor Takeyama has produced some of the best published data to date on the effect of ternary elements on phase equilibrium in several key Ti-Al-X ternary systems, which is key to alloy development. Also of great importance is his work on the modification and control of cast gamma TiAl microstructures through heat treatment. Prof Matsuo has conducted a series of interesting creep studies on cast gamma TiAl, and developed data on the internal stress of a binary TiAl alloy, which can be helpful in calculations of the constituent effects of microstructure on mechanical properties in this class of alloys.

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## 2. OVERVIEW AND BACKGROUND

The Tokyo Institute of Technology (TIT), or Tokyo Kogyo Daigaku in Japanese, is considered one of the premier technical universities in Japan, ranking in many disciplines with the prestigious three "Imperial Universities" of Japan, the University of Tokyo, Kyoto University, and the Tohoku University. TIT is a public, nationally supported institution which was founded in 1929 as an outgrowth of the Tokyo Higher Technical School. It was at this point the TIT became a degree conferring university. The main campus is located in an outlying area of Tokyo known as Ookayama. There is also another campus, the Nagatsuta Campus, which is located in Yokohama.

The institute offers BS, MS, and PhD degree's in various disciplines of science and engineering. The institute currently has approximately 6,000 undergraduate and around 2,500 graduate students. The institute is divided into three faculties: the Faculty of Science, with 6 departments; the Faculty of Engineering, with 16 departments; and the newest faculty, the Faculty of Bioscience and Biotechnology.

Most of the facilities at the Nagatsuta Campus, which include the new Faculty of Bioscience and Biotechnology, are housed in fairly modern facilities. However, many of the departments at the main Ookayama campus are housed in somewhat old and run-down facilities. The Ministry of Education (Monbusho) is renowned for it's generous building budgets, but almost non-existent maintenance budgets, so many of the national universities such as TIT have crowded, dingy facilities. A major building project is scheduled to begin in several years to replace most of the older buildings at the Ookayama campus.

Although all of the operating budget comes from Monbusho, Monbusho only provides approximately 70% of the research budget for a typical department, and the remainder of the funds come from industry. Within this private sector funding, the majority are given as grants. In 1992, the research grants totaled \$18.21M, while the Endowed Chairs, Contract Research and Joint Research programs totaled \$2.8M, \$2.6M, and \$2.1M, respectively. In the case of the Metallurgical Department, the majority of this industrial support comes from steel companies in Japan primarily to perform research on research on steel alloys.

There is a drive at the institute to increase the number of students from abroad. Currently there are over 500 foreign students at TIT, the majority in the graduate schools. Most of the foreign students come from China (42%) and Korea (24%), with only a handful of European or American students. In order to encourage enrollment of foreign students, graduate courses attended by foreign students are taught in English.

## 3. DISCUSSIONS

My visit to TIT was arranged and hosted by:

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This visit was a result of a long-standing invitation from my colleague Prof Takeyama, who is active in research on intermetallic material systems, including gamma TiAl alloys. It was also hoped that I could meet with the head of this research group, the eminent Professor Makoto Kikuchi. However, Prof Kikuchi is still in poor health, recovering from a heart ailment which incapacitated him last year.

I was given a brief overview of TIT by Prof Matsuo. Following that overview, I gave a brief seminar on microstructure/property relationships in gamma TiAl alloys to several members of the faculty and a handful of graduate students.

Prof Takeyama arrived at TIT in 1992 from the Science and Technology Agency (S&TA) National Research Institute for Metals (NRIM) which is located in Tsukuba. While at NRIM Prof Takeyama performed research on phase stability and transformations of several intermetallic alloy systems, including gamma TiAl. Since coming to TIT, Prof Takeyama has broadened this research to include microstructure/property effects, with the emphasis on the effect of static heat treatments on microstructure and properties, while continuing his research on the effect of ternary additions to the phase stability of near gamma alloys. The majority of the phase stability work in Ti-Al-X systems have been where X is Cr, Nb, V or Mo.

Of potential commercial significance is Prof Takeyama's work on air cooling and rapid quenching from the single phase alpha region, followed by tempering or aging. Prof Takeyama has demonstrated it is possible to use quench and tempering treatments to refine the as-cast structure, thus improving the room temperature strength and ductility over typical coarse cast microstructures.

One of these studies was performed on a high Nb ternary alloy (Ti-43Al-15Nb), which was a two-phase gamma/B2 at room temperature. The sample was water quenched from 1377°C, which is the beta single phase region. The martensitic quenched structure is then tempered at 1050°C for 24 hours. The resulting microstructure is a 20-30  $\mu\text{m}$  microstructure of coarse platelet gamma and B2. In the as-quenched condition, this alloy failed without yielding in an almost completely brittle manner, with a fracture strength of about 1700 MPa. Following the temper treatment, the sample exhibited a ductile failure, with a YS of approximately 1050 MPa, and a plastic elongation of approximately 1.5%.

In a similar study, this time on a Ti-46.5Al-3.5Cr alloy, a sample was heat treated in the single phase alpha field at 1330°C, and then quenched. The massively transformed microstructure was then tempered at 1040°C for 24 hours, producing a fairly fine, equiaxed gamma/B2 microstructure with a grain size of approximately 20-30  $\mu\text{m}$ . The tensile properties of the as-quenched alloy was a brittle failure after slight yielding, at 790 MPa. The tempered sample, on the other hand exhibited ductile behavior, with a yield stress of approximately 460 MPa, UTS of approximately 590 MPa, and a total strain in excess of 4%.

These results are important, not only because of the absolute properties of the tempered samples, but also as an indication of a potential route towards microstructural control and property improvement through static heat treatments of cast structures.

In addition to the TiAl work, several of Prof Takeyama's students are pursuing projects in other "model" intermetallic systems. Most of these studies are fundamental in nature, and are examining phase transformation phenomenon in ordered systems.

Following a review of Prof Takeyama's research on gamma TiAl, I then met with Prof Matsuo, to discuss his work on creep of cast gamma TiAl alloys. Most of the research to date has been published in Japanese, and the Prof has not yet had time to translate them and submit them to English language journals because of a sabbatical last year in France. All of the creep experiments have been performed on binary alloys, with the composition Ti-50Al. The as-cast microstructure was coarse dendritic lamellar colonies, with approximately 20-30 vol % interdendritic gamma. Because of the high Al in this alloy, it is especially susceptible to microstructural modification by heat treating near the eutectoid temperature, where the microstructure will transform from a nearly-lamellar microstructure to a near-gamma microstructure, primarily with equiaxed gamma grains. The majority of the creep experiments were conducted contrasting these two microstructures, which were referred to as "as-cast", and "homogenized."

As might be expected, due to the chemical and structural non-equilibrium nature of the as-cast material, which reportedly also contained a high density of dislocations, the comparison between the creep resistance of the nearly-lamellar vs. the equiaxed gamma microstructure is somewhat clouded.

Compared with the creep work of Prof Oikawa, whose research focused mainly on the high stress/high strain rate creep in compression, Prof Matsuo's tensile creep experiments are confined primarily to the high temperature/low stress region of 800-900°C, and stress levels on the order of 40 to 240 MPa, which is well below the yield stress of the alloys tested. Other interesting features of his research were stress dip tests to ascertain the internal stress of the alloys, and to investigate the role of dynamic recrystallization in creep.

Some of our discussions centered around inherent creep resistance of the fully lamellar microstructure, and whether the good creep resistance is primarily due to the grain size effect (Prof Matsuo's contention), rather than other potential microstructural features such as the lamellar microstructure, interlocking lamellar grain boundaries, etc. Fully lamellar microstructures generally have very coarse grain sizes, while it is very difficult to produce homogeneous duplex or two-phase equiaxed microstructures with coarse grain sizes. Single phase gamma alloys may be heat treated to a variety of grain sizes, but the potential effect of the alpha-2 phase is lost, not to mention the differences in Al concentration of the gamma phase. It was agreed that the best way to settle this issue is by performing comparative creep tests with a fine grained lamellar microstructure vs. a coarse duplex or two-phase equiaxed microstructure.

His data also supports the contention that polycrystalline single phase gamma alloys are superior to the fully lamellar microstructure in creep resistance. Again, it is difficult to interpret such data, because of the difficulty in separating potentially important effects such as the Al concentration of the single phase alloy on strength, vs. the strength contribution of the alpha-2 phase, the importance of microstructural features in the lamellar microstructure, etc.

#### 4. SUMMARY AND COMMENTS

The Tokyo Institute of Technology has an active and well known Materials Science program in Japan. Although much of the research conducted in the Department of Metallurgical Engineering is in support of the Japanese steel industry, a considerable

amount of research on advanced structural materials, such as intermetallic alloys is also being conducted. Although some of the facilities at TIT are in very poor condition, the equipment and faculty are very good. In fact, it seems that there is an inverse relationship between the quality of the facilities, and the quality of the faculty and research at many of Japan's universities.

Professor Takeyama has produced some of the best published data to date on the effect of ternary elements on phase equilibrium in several key Ti-Al-X ternary systems, which are key to alloy development. Also of great importance is his work on the modification and control of cast gamma TiAl microstructures through heat treatment.

Prof Matsuo has conducted a series of interesting creep studies on cast gamma TiAl, and developed data on the internal stress of a binary TiAl alloy, which can be helpful in calculations of the constituent effects of microstructure on mechanical properties in this class of alloys.